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Evaluating Black Walnut Planting
Stock Quality¹

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INTRODUCTION

Work with hardwood species in the southern and central United States has indicated that root system morphology can be a major determinant of seedling success (or failure) in the field (Kormanik, 1986; Schultz and Thompson, 1990). Survival and shoot growth after transplanting depend to a great extent on the seedling root system and the ability of the seedling to rapidly produce new roots (Farmer, 1975; Sutton, 1980; Burdett et al., 1983; Kormanik et al., 1988; Rietveld and van Sambeek, 1989; Barden and Bowersox, 1989). Especially for stock cultured in bareroot nurseries, the potential for new root production (root growth potential) can be related to the presence of an adequate system of relatively large (> 1 mm proximal to the taproot) permanent first-order lateral roots (FOLR) (Thompson, 1991). FOLR that arise within the portion of the taproot that is lifted are generally able to survive the rigors of lifting, packing, storing, shipping, and planting procedures, and provide sites for initiation of new roots during the seedling establishment phase (Thompson and Schultz, 1995). Periodic seedling excavations have indicated that these roots do persist after planting (e.g. Thompson, 1991).

Forest nurseries in five states (Illinois, Indiana, Iowa, Missouri, and Ohio) established a cooperative in 1987 to improve cultural control of hardwood seedling morphology. Other states, including Wisconsin and Minnesota, have participated in some studies. Preliminary evaluation of bed-run 1+0 bareroot stock from several nurseries before studies were initiated indicated that 28-33% of black walnut seedlings had fewer than five FOLR (Schultz and Thompson, 1990). Early work of the cooperative emphasized practices that might increase

1 numbers of FOLR on seedling root systems. Control of seedbed density and use
2 of undercutting were the initial treatments chosen for study. Subsequent
3 studies also outlined in this paper examined genetic aspects of root morphology
4 and response to undercutting, and effect of tree shelters on seedling growth and
5 plantation establishment.

6 Although red oak (Quercus rubra L.), white oak (Quercus alba L.), and
7 black walnut (Juglans nigra L.) seedlings were included in these studies, results
8 for only black walnut seedlings are presented here.

10 MATERIALS AND METHODS

11 Density plots were established in regularly planted beds of rising 1-0 open
12 seedlot black walnut stock in spring 1987 in the state nurseries of Illinois, Iowa,
13 and Missouri by using a 0.3-m grid to achieve uniform density. Thinning was
14 done where necessary by clipping one stem of closely spaced seedlings. Black
15 walnut were thinned to densities of 32, 64, or 96 stems per m². Half of the
16 density plots were undercut at a depth of 15-20 cm when the taproots were 6.0
17 to 13.0 mm in diameter at a depth of 15 cm. Each density-undercutting
18 combination was replicated in the nursery beds 5 to 6 times. Plots received
19 fertilizer, weeding, and irrigation treatments customary at their respective
20 nurseries. Seedlings were lifted during spring 1988; 40 seedlings were randomly
21 selected for evaluation and field planting from each of the replications (for a total
22 of 200 to 240 seedlings per treatment).

23 Seed for the study on genetic influences on walnut seedling root morphology
24 was grown in plots by mother tree in Illinois, Iowa, Missouri, and Ohio nurseries
25 during the 1988 season. All seedlings were grown at densities of 64 stems per
26 m² and were not undercut. Numbers of seedlings grown per parent tree varied

1 from 35 to 90 according to availability of seed. Again, seedlings received
2 fertilizer, weeding, and irrigation treatments customary at their respective
3 nurseries.

4 Stock used in the plantation establishment study with tree shelters were
5 grown in their respective nurseries during the 1990 season. These seedlings
6 were sorted into 6 groups based on numbers of roots (0-6, 7-11, and 12+) and
7 whether undercut or not.

8 For all three studies, seedlings were measured before planting to determine
9 (1) height from the root collar to the base of the terminal bud, (2) diameter at
10 approximately 1.3 cm above the root collar, and (3) the number of first order
11 lateral roots >1mm, including a separate assessment of FOLR that resulted
12 from undercutting (wound roots arising at or just above the point of
13 undercutting).

14 Seedlings were outplanted (density/undercutting study planted in spring
15 1988, progeny tests planted in spring 1989) in their respective states as
16 completely randomized individual tree plots, except for the plantation
17 establishment study, which was planted in spring 1991 as a split-split plot
18 design. For this study, 8 replications of 10 seedlings from the 6 groups were
19 planted for each of 2 planting methods, for a total of 960 seedlings. Tree shelters
20 were installed on half of the seedlings at the time of planting.

21 For the density/undercutting and genetic studies, seedlings were planted at
22 a 1.2-m x 2.4-m spacing by using a two-person power auger with a 20-cm
23 diameter bit. In the plantation establishment study, half of the seedlings were
24 planted using a power auger, and half were planted with a large hardwood
25 planting machine. A 2.4-m x 3.0-m spacing was used, with crop trees placed in
26 alternate rows. "Nurse" tree species included white pine and green ash.

Height and diameter were measured at the end of each growing season 1988 (1989 or 1991) through 1992, and then again in 1994. Data were analyzed and ANOVA done using the GLM procedure of SAS (SAS, 1989).

RESULTS AND DISCUSSION

For brevity, only data from selected states involved in these studies will be presented in this paper. Results are presented for (1) density and undercutting treatment effects on FOLR (1988 study) in Illinois and Missouri; (2) seedling survival and growth related to FOLR (1988 study) in Missouri; (3) genetic influences on FOLR (1989 study) in Ohio; and (4) seedling establishment with tree shelters (1991 study) in Iowa.

1. Number of FOLR per treatment. Effects of bed density and undercutting on number of FOLR for black walnut grown in Illinois and Missouri are shown in Table 1. At a given density, seedlings that were undercut had greater numbers of FOLR. This was due to both the development of wound roots at the end of the severed taproot, and the thickening of existing lateral roots above the cut (Schultz and Thompson 1990). Seedlings grown at lower densities had more additional FOLR attributable to undercutting.

Mean number of FOLR for seedlings grown in Illinois ranged from 18 for undercut seedlings grown at 32 m^{-2} to 7 for those grown at 96 m^{-2} and not undercut (Table 1). Differences in number of FOLR due to both density and undercutting were significant at the 0.01 level.

Mean number of FOLR for seedlings grown in Missouri ranged from 16 for undercut seedlings grown at 32 m^{-2} to 8 for those grown at 96 m^{-2} and not undercut (Table 1). These differences were also significant at the 0.01 level. Increases in FOLR at a given density due to undercutting were significant at

densities of 32 m^{-2} and 64 m^{-2} , but there was less difference in number of FOLR between undercut and not undercut seedlings grown at 96 m^{-2} .

The effects of density control and undercutting on numbers of FOLR show that there was an advantage in limiting nursery bed density, and if density was low enough undercutting was beneficial.

Lowering bed density increased the proportion of seedlings that had at least 7 FOLR to 60 % for not undercut seedlings and 80% for undercut seedlings. This was in contrast to data already mentioned for planting stock produced by most nurseries the previous year, probably because seedlings had previously been grown at densities even greater than the maximum densities used in this study. Based on these results bed densities of 32 to 64 m^{-2} are recommended for bareroot culture of 1+0 black walnut. Undercutting seedlings grown at these densities can significantly increase seedling FOLR.

2. Seedling survival and growth. The effects of nursery bed density, undercutting, and numbers of FOLR on 7-year survival for black walnut grown in Missouri are shown in Figure 1.

For Missouri black walnut, there was a slight difference in survival rates between the treatments, with 98% survival for seedlings grown at 32 m^{-2} (both undercut and not) down to 90% for undercut seedlings grown at 96 m^{-2} (Figure 1a). Seventh-year survival vs. number of FOLR for black walnut seedlings indicated good performance of seedlings with at least 7 to 9 FOLR (Figure 1b). These data are consistent with previous analyses of survival versus numbers of FOLR, which indicated these threshold levels to be about 7 to 9 FOLR for black walnut in the central United States (Schultz and Thompson, 1990).

Average numbers of FOLR produced by seedlings in each of the treatment groups were adequate (threshold) numbers of roots for acceptable performance

1 in the field. However, a greater proportion of the seedlings with 4 or fewer FOLR
2 came from the higher density plots that were not undercut than from the lower
3 density plots that were undercut.

4 The effects of density and undercutting on seventh-year height and
5 diameter for Missouri black walnut are shown in Figure 2. Average seedling
6 height ranged from 220 cm for not undercut seedlings grown at 32 m^{-2} to 193
7 cm for undercut seedlings that were grown at 96 m^{-2} (Figure 2a). For the
8 walnut, undercut seedlings grown at a given density were initially much shorter
9 than not undercut seedlings (Schultz and Thompson, 1990), and although they
10 have grown more rapidly than those that were not undercut, on the average
11 they remain slightly shorter. Seedling diameters ranged from an average of 37
12 mm for not undercut seedlings grown at 32 m^{-2} to 32 mm for undercut seedlings
13 grown at 96 m^{-2} (Figure 2b). The trend for seedlings grown at lower densities to
14 be larger than those grown at higher densities continued, although size
15 differences for the black walnut seedlings after 7 years in the field were only
16 significant for seedlings grown at 32 m^{-2} and not undercut compared to all
17 others.

18 Generally, the results of this work indicated that field performance in terms
19 of survival, height, and diameter growth was related to seedling morphology, and
20 that seedlings with adequate FOLR performed better than seedlings with few
21 FOLR. Cultural practices that increased numbers of FOLR improved seedling
22 performance after planting.

23 3. Genetic influences on number of FOLR. Average number of FOLR by
24 parent tree, and 6th-year height and diameter for the Ohio black walnut
25 selections outplanted in 1989 are shown in Figure 3. Mean numbers of FOLR
26 were 10 or greater for all of the selections (Figure 3a). These seedlings were

1 grown at a controlled density of 64 per m², which may have enhanced
2 expression of FOLR. Differences between average number of FOLR between
3 families were significant at the .01 level. Based on work done with separate
4 seedling samples from the same family populations, several morphological
5 traits, including lateral root biomass (closely related to number of FOLR), had
6 relatively high heritability (Feret, 1990). These results suggest the possibility
7 for genetic improvement of seedling root morphology through selection of specific
8 seed sources, in addition to improvement from cultural treatments.

9 Although there were differences in height between families for seedlings
10 outplanted in Ohio (Figure 3b), after 6 years in the field few differences were
11 statistically significant. This may have been due to relatively high average
12 numbers of FOLR for all selections. Differences between average diameter for
13 different families after 6 years were greater. Seedlings from parents T2, T4, T5,
14 and T6 had higher average numbers of FOLR and performed well in terms of
15 both height and diameter growth.

16 4. Seedling establishment with tree shelters. Fourth-year results for
17 sheltered and unsheltered black walnut seedlings from different root grade
18 groups that were hand-planted in Iowa are shown in Figure 4. Average survival
19 rates ranged from 94% for seedlings with 0-6 FOLR grown without shelters to
20 100% for seedlings with 7 or more FOLR grown with or without shelters (Figure
21 4a). Shelters enhanced survival of seedlings with fewer than 6 FOLR slightly.

22 Average height of the seedlings after 4 years ranged from 79 cm for not
23 undercut seedlings with 6 or fewer FOLR without shelters to 173 cm for both
24 undercut and not undercut seedlings with 12 or more FOLR that had shelters
25 (Figure 4b). Four years after planting, seedlings in tree shelters were nearly
26 twice the height of seedlings that were not sheltered. Since sheltered seedlings

1 were so much taller than their non-sheltered counterparts, statistical analyses
2 of height for sheltered and unsheltered seedlings were performed separately. For
3 both sheltered and unsheltered seedlings there were significant differences in
4 average height after 4 years between root grade groups.

5 Average diameter of the seedlings ranged from 16 mm for not undercut
6 seedlings with 6 or fewer FOLR that were not sheltered to 23 cm for not
7 undercut seedlings with more than 12 FOLR that were sheltered (Figure 4b).
8 Even though the sheltered seedlings were dramatically taller than the
9 unsheltered, differences in diameter between them were insignificant. Thus, the
10 height: diameter relationship of sheltered seedlings was unusual. Final analysis
11 of the relative success of sheltered seedlings will be made some time after the
12 shelters decompose or are removed.

13 Consistent trends of increased height and diameter with greater numbers of
14 FOLR were significant and still especially pronounced for the sheltered seedlings.

16 CONCLUSIONS

- 17 1. Lower bed density increased the proportion of seedlings produced that had at
18 least 7 FOLR to 60% for not undercut seedlings and 80% for undercut seedlings.
19 Lowering bed density produced the greatest gain in numbers of FOLR.
- 20 2. Undercutting increased the number of FOLR lifted with the seedlings,
21 particularly for seedlings grown at lower densities. For taprooted species that
22 are likely to leave many roots in the nursery bed when lifted by traditional
23 methods, undercutting can enhance bareroot seedling root systems.

1 3. Evaluation of seedling root systems should be included as a part of routine
2 grading procedures. Black walnut seedlings with 7 or more FOLR are more likely
3 to survive and grow rapidly after outplanting. Morphological root system
4 assessment is rapid and inexpensive, and could be easily integrated into existing
5 grading procedures.

6 4. Preliminary testing of seedlings from different parent trees indicates that
7 genetic improvement of seedling root system morphology for black walnut is
8 possible. Further study should be given to the use of root morphology as a
9 possible selection criteria.

10 5. Although height differences were dramatic between sheltered and unsheltered
11 seedlings, final recommendations on the use of shelters will not be made until
12 some time after the shelters have been removed. Even for sheltered seedlings
13 there were significant height and diameter increases with increasing number of
14 seedling FOLR.

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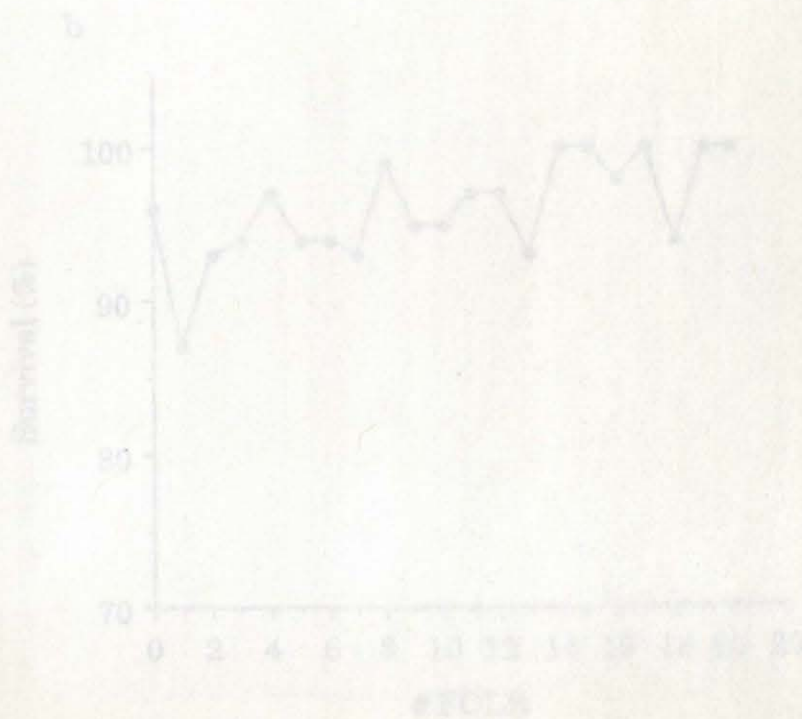
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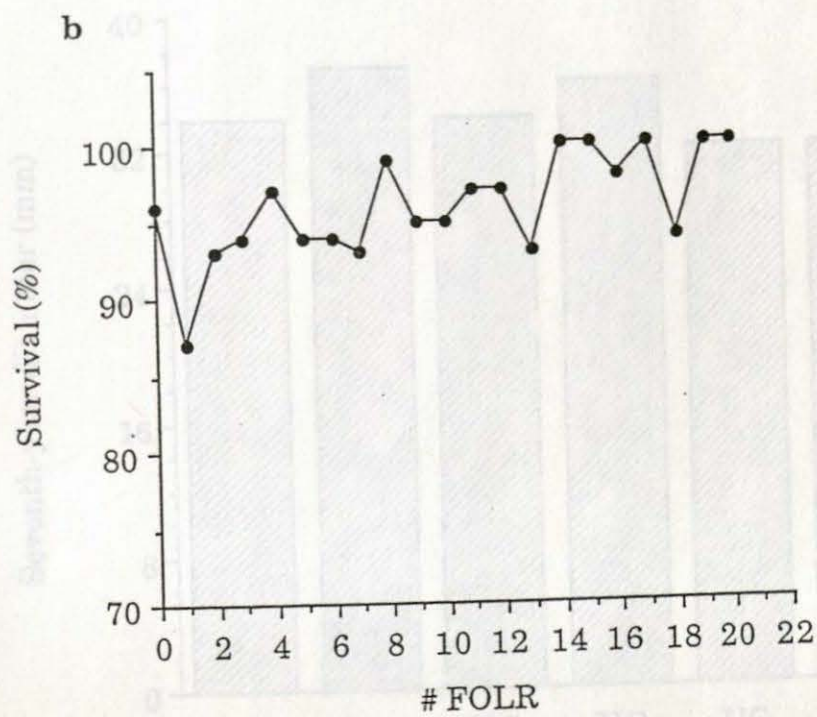
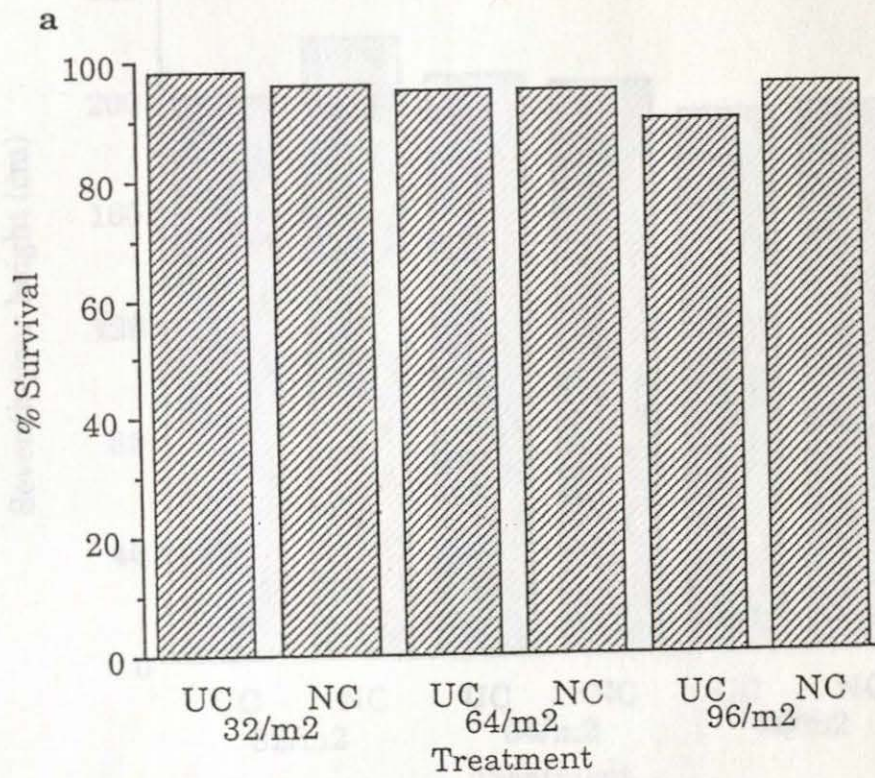
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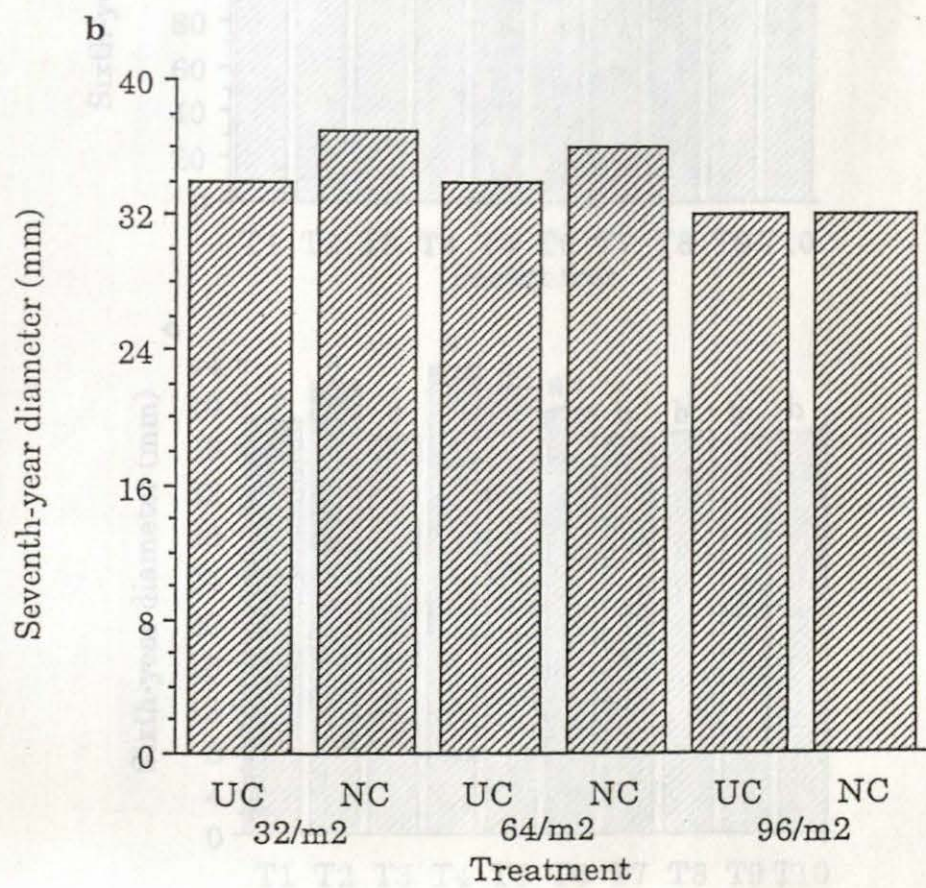
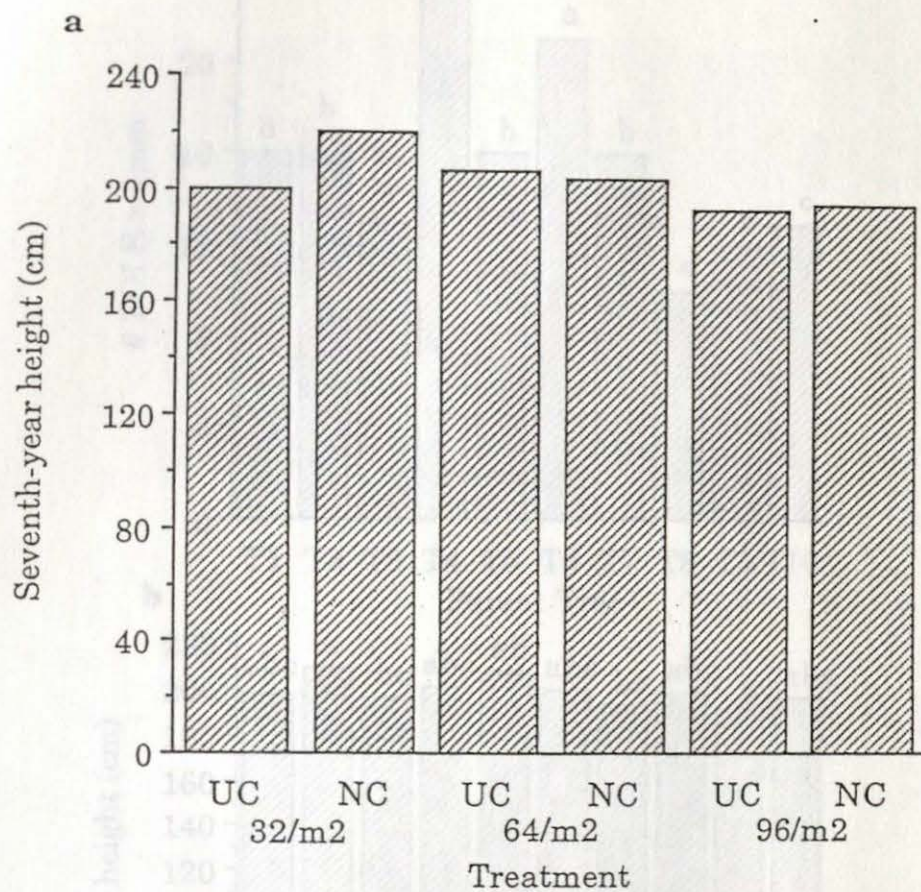
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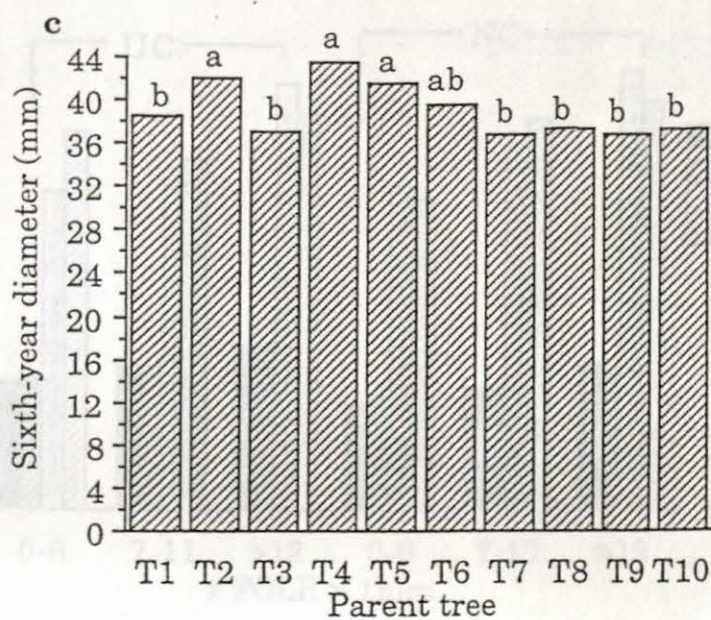
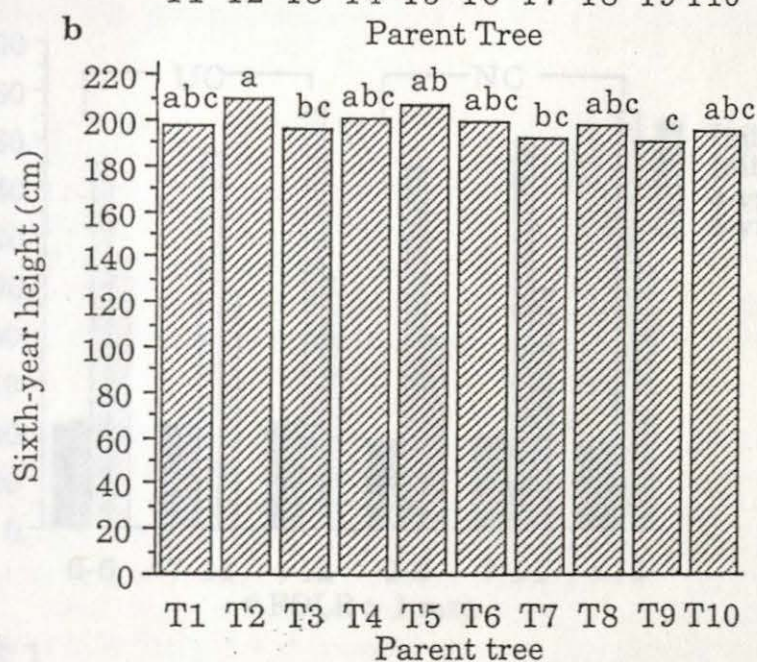
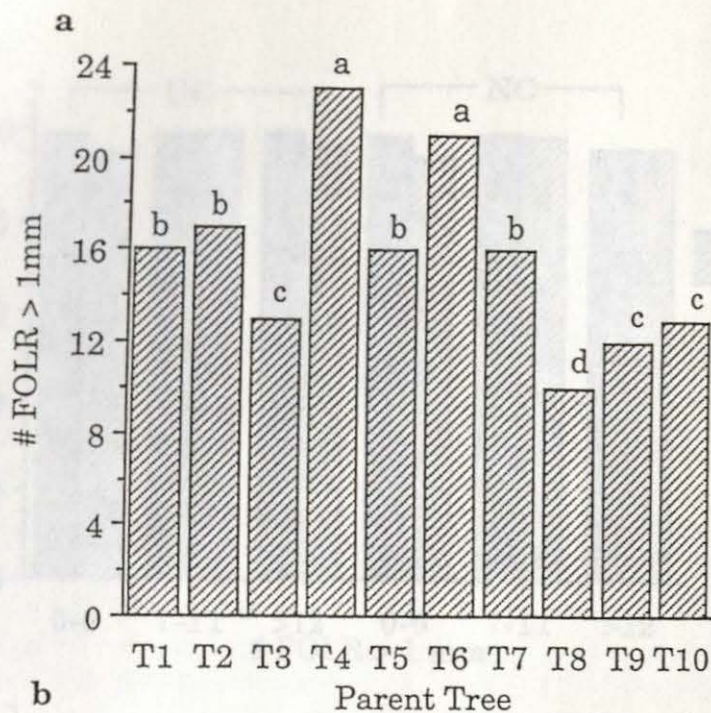
- 2 Table 1. Effects of nursery bed density and undercutting on average number of
 3 FOLR for black walnut grown in Illinois and Missouri. Numbers
 4 followed by the same letter are not significantly different at the .01
 5 level.
- 6 Figure 1. Effects of (a) bed density, undercutting and (b) number of FOLR on 7-
 7 year survival rates for black walnut seedlings grown in Missouri.
 8 UC=undercut, NC=not undercut, numbers indicate seedlings m^{-2} .
- 9 Figure 2. Effects of density and undercutting on (a) height and (b) diameter for
 10 black walnut seedlings grown in Missouri.
- 11 Figure 3. Effects of parent tree selection on (a) number of FOLR, (b) sixth-year
 12 height, and (c) sixth-year diameter for black walnut grown in Ohio.
 13 Different letter designations indicate significance at the .01 level.
- 14 Figure 4. Effects of numbers of FOLR, undercutting, and tree shelters on fourth-
 15 year (a) survival, (b) height, and (c) diameter of black walnut grown in
 16 Iowa.

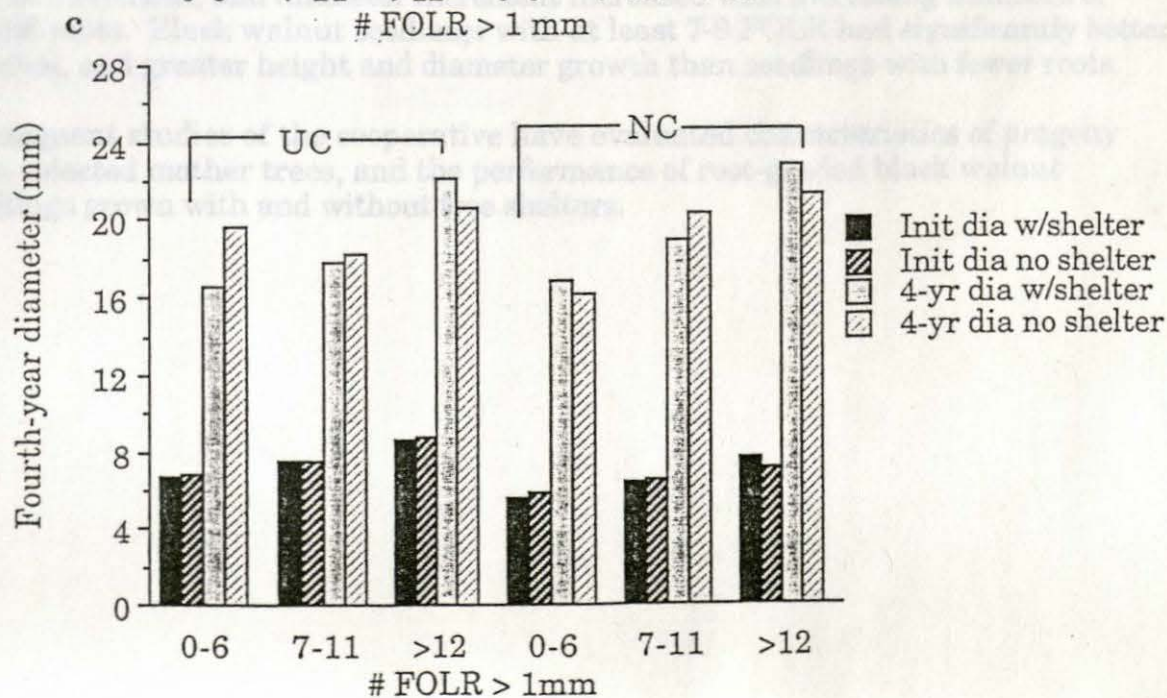
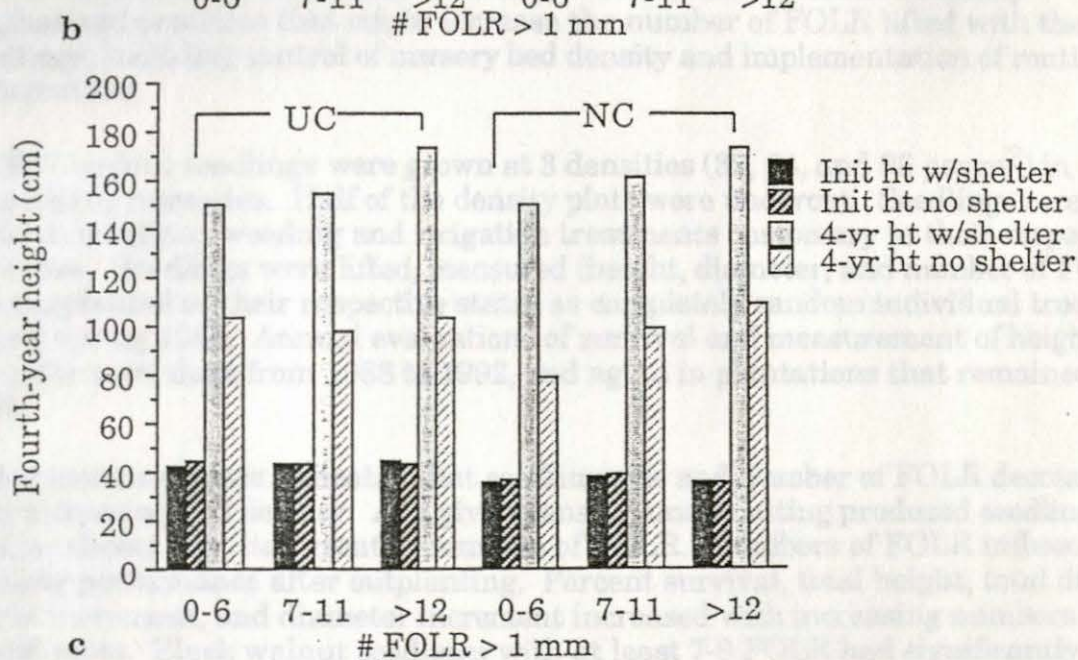
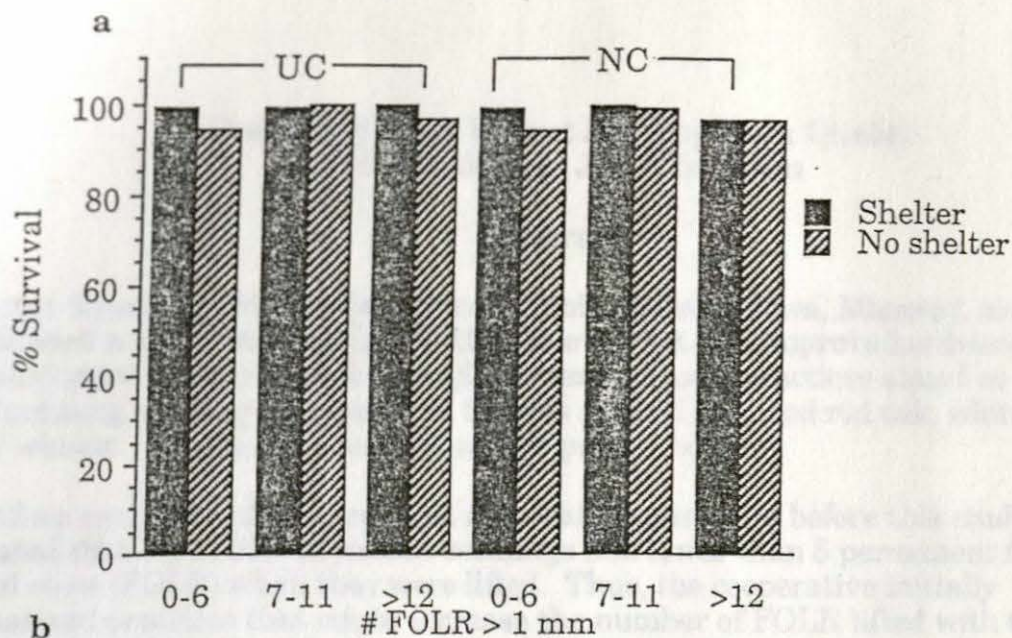
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Abstract

Bareroot forest nurseries in five states (Illinois, Indiana, Iowa, Missouri, and Ohio) established a cooperative project in 1987 to evaluate and improve hardwood seedling morphological characteristics through nursery cultural practices aimed at manipulating seedling root systems. Species studied included red oak, white oak, and black walnut. Results for black walnut are presented here.

A random sample of plants grown at cooperating nurseries before this study began indicated that about 30% of walnut seedlings had fewer than 5 permanent first-order lateral roots (FOLR) when they were lifted. Thus, the cooperative initially emphasized practices that might increase the number of FOLR lifted with the seedlings, including control of nursery bed density and implementation of routine undercutting.

In 1987 walnut seedlings were grown at 3 densities (32, 64, and 96 per m²) in cooperating nurseries. Half of the density plots were undercut. Seedlings received uniform fertilizer, weeding and irrigation treatments customary to their respective nurseries. Seedlings were lifted, measured (height, diameter, and number of FOLR), and outplanted in their respective states as completely random individual tree plots during spring 1988. Annual evaluations of survival and measurement of height and diameter were done from 1988 to 1992, and again in plantations that remained in 1994.

Initial measurements indicated that seedling size and number of FOLR decreased with increasing bed density. At a given density, undercutting produced seedlings with smaller shoots that had greater numbers of FOLR. Numbers of FOLR influenced seedling performance after outplanting. Percent survival, total height, total diameter, height increment, and diameter increment increased with increasing numbers of lateral roots. Black walnut seedlings with at least 7-9 FOLR had significantly better survival, and greater height and diameter growth than seedlings with fewer roots.

Subsequent studies of the cooperative have evaluated characteristics of progeny from selected mother trees, and the performance of root-graded black walnut seedlings grown with and without tree shelters.